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Spatial data for national fire planning and fuel management

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Abstract. Spatial data products are most often developed to support resource management decisions. Rarely can the data stand by themselves as spatially-explicit risk assessments. We discuss the technical aspects of true risk assessments, and the contrast between risk assessments and the underlying spatial data that an agency might use to perform one. We then present the development methodology and results from a comprehensive, national effort at creating resource data products that may be useful in agency- or geographically-specific risk assessments.

We have produced a suite of spatial data layers, each a continuous coverage for the conterminous United States, to support national-level, programmatic planning efforts for fire and fuel management. This document describes the development of seven data layers: (1) Potential Natural Vegetation Groups; (2) Current Cover Types; (3) Historical Natural Fire Regimes; (4) Current Condition Classes; (5) National Fire Occurrence; (6) Potential Fire Characteristics; and (7) Population Density Groups. This paper documents the methodology used to develop the spatial products. We used a Geographic Information System (GIS) to integrate biophysical and remote sensing products with disturbance and succession processes. We then assigned attributes developed from succession diagrams to combinations of biophysical, current vegetation, and historical fire regime data layers. Regional ecologists, silviculturists, and fire managers developed the succession diagrams, reviewed and refined the data layers, and assigned condition classes.

None of these data layers were developed to stand alone as an integrated risk assessment. Technically-robust risk assessments require quantification not only of the probability of an event occurring—wildland fire in this case—but also of the values at risk of damage or loss. The 'values' component of a risk assessment is highly dependent on the resource management policies and objectives of the responsible agency. The data presented here were developed for integration by individual agencies into agency-specific plans and risk assessments. For example, planners will use the Current Condition Class data to allocate resources for fire and fuel management. These data are posted on the national, USDA Forest Service website http://fs.fed.us/fire/fuelman.

Introduction

Characterizations of fire hazard and associated risks are currently underway at many temporal and spatial scales. At the relatively fine-grain spatial scale of an individual management unit (such as a Forest Service Ranger District), assessments of local fuel loadings and fire hazards are commonly done for short-term planning and execution of tactical treatments as well as for long-term, strategic planning. Coarser-grained characterizations—often referred to as 'coarse-scale assessments'—have received recent attention in the form of regional scientific assessments such as the Interior Columbia Basin Ecosystem Management Project (Quigley *et al.* 1996), and the Sierra Nevada Ecosystem Project (University of California 1996). National as well as global map products are also being developed to support assessment, monitoring, and reporting of carbon sources and sinks. Wildland fire and fire management activities are important contributors to carbon fluxes, and the UN Framework Convention on Climate Change calls for national and international mapping efforts (United Nations 1992).

Several national initiatives by Federal land management agencies in the United States have resulted in development of, and reliance on, spatially-explicit data relating to vegetation cover types, historical disturbance regimes, and

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current conditions. These projects are typically motivated by the need to perform an analysis of conditions and consequent management needs, ultimately leading to a setting of priorities and even a long-term time schedule for treatments. In this regard, the strategic planning resulting from such an analysis takes the form of a 'triage', not unlike the battlefield medical system designed to produce the greatest benefit from limited treatment resources. A triage system is used to allocate a scarce commodity only to those capable of deriving the most benefit.*

This paper does not provide a comprehensive synthesis of risk assessments or management as they relate to fire and fuels management. Rather, we use a project that encompassed the entire conterminous U.S. (CONUS) as its mapping domain to illustrate an ecologically-based suite of protocols for assessing fire- and fuels-related attributes. While the project was implemented in response to specific national-level strategic planning needs, we present it here as an example of how various map products can be integrated and applied.

Before we present details of the specific project, however, we must address the terminology, expectations, and limitations of most spatial assessments with respect to the technical details of a classic risk assessment.

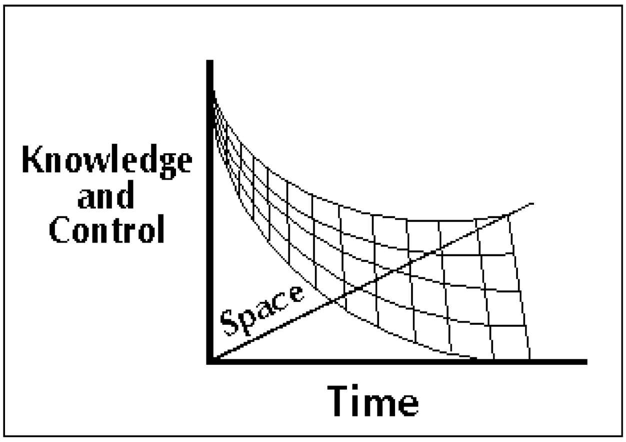


Fig. 1. Both knowledge and control are dependent on scales of space and time.

Resource layers versus risk assessments

In the conference and proceedings from the Joint Fire Sciences Conference and Workshop, 'Crossing the millenium: Integrating spatial technologies and Eecological principles for a new age in fire management', 17 papers were presented on various aspects of mapping, and an additional 9 specifically addressed fire hazard and risk. These papers addressed such subjects as evaluating risks and benefits, fire-based hazard/risk assessments, ecological approaches to fire hazard assessment, spatial modeling of fire hazards, and fire probability mapping.

The project we present here, as well as many other similar projects, have been mistakenly called 'risk mapping' projects. Both the data and the tools with which to analyse them in a truly spatial context have only recently become available to resource managers, and accompanying expectations have been considerable regarding the potential to exploit them. Perhaps highest among these expectations is that risks are 'mappable', and that such maps can be used by multiple agencies for both strategic and tactical decision-making at multiple scales of time and space. No suite of maps can do that, for several reasons. First, in the context of technical risk engineering terminology, risk is defined as the product of the probability of an event occurring—wildland fire in this case—and the values at risk of damage or loss. The 'values' component of a risk assessment is highly dependent on the resource management policies and objectives of the responsible agency. Second, neither of the two terms in the 'risk equation' (event probability and values) can integrate more than two resource functional areas, probabilities and values, for many resource functional areas are simply not congruent. Third, appropriate accuracy and precision standards will most often be quite different between products developed for strategic decisions versus those developed for tactical decisions. As illustrated in Fig. 1, we know that tradeoffs are always made between the required levels of both knowledge and control (the vertical axis) and scales of time and space (the two horizontal axes). That is, we 'give up' knowledge or control with decreases in the spatial or temporal resolution of our data. This is often not a large 'cost' at the national level of program planning. On the other hand, where tactical decisions are required, we require a high degree of knowledge and control, with the concomitant demand for increases in both temporal and spatial resolution. The practical consequence of this is the need for more than one kind of map product. Finally, the damage/value aspects of risk are clearly dependent on the resource management policies and objectives of individual agencies, thereby limiting practical development and application of integrated 'risk maps' to each agency or, at the tactical level, to individual administrative units within an agency.

The 'Coarse-scale project' as a case example

The objectives for this project were to develop primary spatial data products for the CONUS for use by individual agencies in their national-level, programmatic planning. Throughout this document, the only explicit references to risk are related to '*the relative risk of losing key components that define an ecosystem*'. As we will explain, this definition of risk is used in our characterizations of **current condition**, as contrasted to the **historical natural fire regime** conditions—our biophysical baseline.

* The American Heritage Dictionary, Second College Edition (1982) Houghton Mifflin Company.

This mapping effort to provide data for national-level risk assessments and fuel management decisions (hereafter called the 'coarse-scale project') was initiated as two associated projects under the responsibility of the Fire Modeling Institute at the Fire Sciences Laboratory, Rocky Mountain Research Station, in Missoula, Montana. The first project, called *Fire Regimes for Fuels Management and Fire Use*, began in 1997 through an agreement with USDA Forest Service, State and private forestry, and USDA Forest Service Aviation and Fire Management. The second project, called *Ecosystems at Risk*, was undertaken to add a fire-related component to the USDA Forest Service's *Forests at Risk* project. The Joint Fire Sciences Program subsequently funded these two projects to develop several additional spatial data *layers* (i.e. coverages, a set of thematic data, usually representing a single subject matter). We have produced seven spatial data layers in support of this project, each a continuous coverage for the CONUS, at a 1 km^2 resolution.

Background

Combined policies of fire exclusion and aggressive fire suppression activities have been successful for approximately 80 years (Pyne 1982). This, when combined with extensive changes in land use patterns, has altered fire regimes, fuel loadings, and vegetation composition and structure (Barrett *et al.* 1991; Brown *et al.* 1994) and has increased both the number and the intensity of wildfires (US GAO 1999). While managers have long recognized the need to reduce excessive fuel accumulations to decrease the threat of catastrophic wildfires, they have lacked the fire-related data necessary to implement a National-level strategic plan to conserve and restore ecosystems. The questions managers now need to answer to accomplish aggressive new fuel management goals include:

- What are the current conditions as they relate to historical fire regimes (a biophysical baseline)?
- Where are these excessive fuel accumulations? At what levels?
- What are the most cost-effective actions to reduce fuel levels and to restore ecosystems to historical conditions?
- What are the effects of fuel reductions on other resources (US GAO 1999)?

The national mapping effort described here has now provided managers with data developed from scientific and ecologically-based methods to address these questions.

Biophysical and vegetation-based spatial data

Many ecosystem characteristics can be modeled by assigning attributes to combinations of biophysical and vegetation spatial data layers. The advantages of this methodology include the familiarity that many managers have with these biophysical and vegetation classifications, the large body of research that utilizes this methodology, and the applicability of this methodology to multiple spatial scales. Quigley *et al.* (1996) used a biophysical layer, potential vegetation, and two vegetation layers—cover type and structural stage—to describe ecosystem attributes such as fuel characteristics, wildlife habitat, fire potential, and hydrology. Keane *et al.* (1998, 2000) used this suite of biophysical and vegetation layers to assign fuel characteristics to the Selway–Bitterroot Wilderness, Montana and to the Gila Wilderness, New Mexico. Shao *et al.* (1996) used potential vegetation types to refine a cover type classification. We used this methodology as well as expert opinion to map current condition classes, fire regimes, and also to refine the vegetation layers.

One of the most critical data layers developed to assess ecosystem conditions, and the departure from historical conditions, was the Historical Natural Fire Regimes layer. Fire regime data, expressed in terms of fire frequency and severity, provided a context with which to determine departure from historical conditions—a context necessary to construct succession diagrams and to assign current condition classes. Morgan *et al.* (2001) define fire regimes as 'the nature of fire occurring over an extended period of time'. Heinselman (1983) defines fire regime as 'the kind of fire history that characterizes an ecosystem', with three elements describing the fire regime: fire type and intensity, size, and frequency or return intervals. Fire regime classifications vary, depending upon biome and application. The most current, comprehensive synthesis of fire regime classifications is provided in the new *Effects of Fire on Flora* volume of *Wildland Fire in Ecosystems* by Brown and Smith (2000).

Many alternatives exist for mapping fire regimes. At coarse scales, fire regimes have been mapped using expert opinion and succession pathway decision rules. Morgan *et al.* (1996) used this approach for mapping fire regimes for the Interior Columbia River Basin Assessment Project, an 820 000 km^2 area in the north-western United States. Statistical or simulation models using fire history data have been used at mid to fine scales (Keane and Long 1998; Long 1998; McKenzie 1998). Fire regimes have been mapped at the fine scale by using both fire history records and fire perimeters (Lineback *et al.* 1999). Unfortunately, this level of data is not available at a national level (Heyerdahl *et al.* 1994; McKenzie 1998). We used the expert rule-based approach because of the large (coarse-scale) geographic area of interest. The expert opinion approach also allows the maps to be modified as new data become available (Morgan *et al.* 2001. While departure could have been assigned to the fire ecology succession pathways using methods by Kessel and Fischer (1981), Bradley *et al.* (1992*a*, 1992*b*) and Smith and Fischer (1997), their research did not apply to the entire CONUS. Again, the expert opinion element of this project enabled a more direct linkage between historical fire regimes and current conditions for all lands in the CONUS.

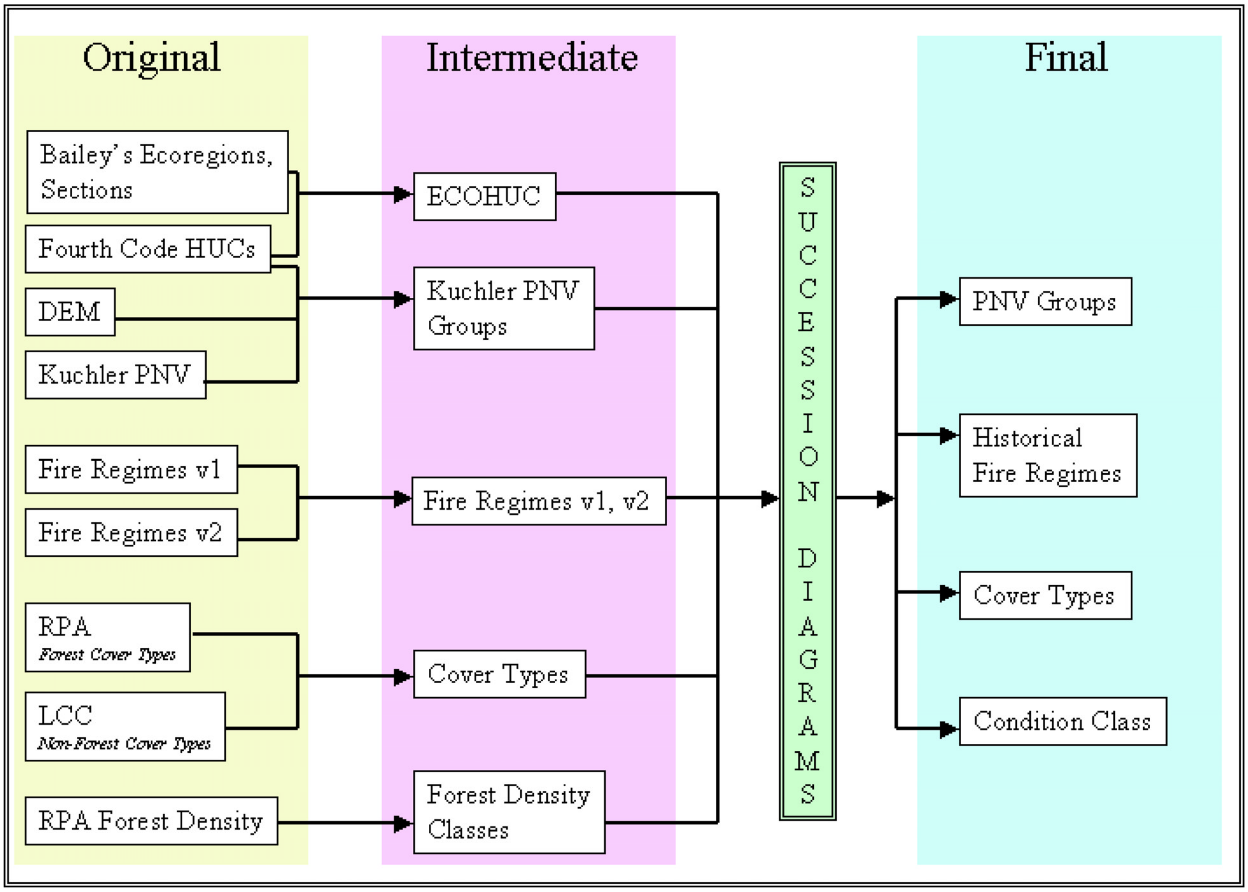


Fig. 2. Flow diagram of spatial data layer development.

Methods

The following sections describe the methods used to develop the seven fuel management spatial data layers*. Four of these seven final layers are expressions of vegetation and biophysical conditions. Figure 2 illustrates the development flow leading to the four final biophysical data products, beginning with 10 original, pre-existing layers which were integrated into 6 intermediate layers. We will discuss the development of succession diagrams and how these interim layers were then used to create the following four biophysical spatial products:

- Potential Vegetation Groups;
- Current Cover Type;
- Historical Natural Fire Regimes; and
- Current Conditions

In addition to the four biophysical spatial products, we developed three other layers for use in strategic fuel management planning. These three are ancillary products developed independent of vegetation or biophysical data. They include:

- National Fire Occurrence, Federal and State Lands, 1986–1996;
- Potential Fire Characteristics; and
- Population Density Groups .

Development of intermediate biophysical spatial data

Six intermediate biophysical data layers were created in the process of developing the final products. These interim layers resulted from modifications to, and integration of, several pre-existing spatial data layers (Fig. 2). Selection of appropriate pre-existing spatial data layers was based on availability, quality, and continuity of data for the CONUS (the lower 48 states). All working data layers—pre-existing, interim, and final—were converted to raster at a 1 km^2 pixel size. The methods described below for each of six interim data layers were first completed for all lands within each USDA Forest Service regional administrative boundary; results were then combined to produce the final versions.

* Data presented at the 1999 Joint Fire Science Conference were initial versions of these products. The final versions, called '*Version 2000*', are presented here, and the reader should note that the final data supersede any previous data presented, published, or posted on any website.

1. ECOHUC

The first interim data layer, called the **ECOHUC** layer, is a combination of Bailey's **Eco**regions, Sections (McNab and Avers 1994; Bailey 1995;) and Fourth Code Hydrologic Units (**HUC**) (Seaber *et al.* 1987). This provided a broad, biophysical stratification.

2. ECORegions

We separated the eight conterminous U.S. Forest Service regions into ecological units, rather than political units. We delineated the Ecological Regional Boundaries (ECORegions) by merging multiple **ECOHUC** Sections to contain each Forest Service **region**. ECOHUC Sections too large to represent one Forest Service region were further divided by using the Fourth Code HUC layer.

3. Potential Natural Vegetation Groups

The Potential Natural Vegetation (PNV) Groups layer, represented site characteristics such as soils, climate, and topography in terms of climax vegetation types. We used Kuchler's Potential Natural Vegetation as the base layer (Kuchler 1975) and then matched it to terrain by using a Digital Elevation Model (DEM). We also grouped the original 118 Kuchler PNVs into 63 PNV Groups classes based on similarity of vegetation types.

4. Historical Natural Fire Regimes

The interim Historical Natural Fire Regimes data layer was a combination of two previous versions. The first version was a prototype product developed for the CONUS using expert knowledge to assign fire regimes to General Land Cover Classes—generalized classes aggregated by Loveland and Ohlen (1993) from their more detailed Land Cover Characterization Database (Loveland *et al.* 1991) discussed in the next section. For the second version, we integrated expert knowledge, remote sensing, and biophysical data to map fire regimes (Hardy *et al.* 1998). The second version was limited to the 11 conterminous western states, from Washington south to California, east to New Mexico, and north to Montana. We used a methodology similar to that used by Brown *et al.* (1994) to develop Versions 1.0 and 2.0. They used site characteristics, habitat types, topographic attributes, and vegetation to map fire regimes for the Selway–Bitterroot Wilderness of Montana. The final version (2000) consolidates all previous fire regime layers into one product for the CONUS.

5. Current Cover Type

We used two remote sensing vegetation data layers to develop the interim current cover type layer: (1) the 1993 Forest and Range Resource Planning Act's (RPA) layer of U.S. Forest Types Groups (Zhu and Evans 1992) for forest cover types; and (2) the Land Cover Characteristics Database (Loveland *et al.* 1991), for non-forest cover types. Both data layers were derived from 1 km^2 resolution Advanced Very High Resolution Radiometry (AVHRR) satellite imagery, and the two products were the only spatially-explicit cover type classifications for all lands in the CONUS.

For the 1993 assessment, the Southern Forest Experiment Station, Forest Inventory and Analysis Unit (SO-FIA) developed a layer of forest types and densities of the United States using 1991 AVHRR data (Zhu and Evans 1992; Zhu 1994). The forest types layer was developed using an unsupervised classification based on statistical clustering of five spectral channels (visible through thermal wavelengths) and a normalized difference vegetation index (NDVI) channel for several different regions (Zhu and Evans 1992). Identification of the unsupervised classification cover types was based mostly on SO-FIA survey plot data. Other sources included the major forest types map, Kuchler's Potential Natural Vegetation map (Kuchler 1964), State and local vegetation maps, the Land Cover Characterization Database (Loveland *et al.* 1991), Landsat images, aerial photos, and SO-FIA survey publications (Zhu and Evans 1992).

Next, we stratified the 159 Land Cover Characteristics Database classes into 26 General Land Cover Types (GLCTs), which we expanded from the 17 dominant cover classes used by Burgan *et al.* (1999) based on additional analysis of plot data collected by Burgan *et al.* (1999). We then combined the GLCT layer with RPA Forest Cover Groups layer to produce an interim Current Cover Type layer. All non-forest areas of the RPA Forest Cover Groups were replaced with GLCTs.

6. Forest Density Class

The last interim product we developed was the Forest Density Class layer, a reclassification of a Forest Density layer developed by the SO-FIA for the 1993 RPA assessment. The original RPA Forest Density layer was developed as a surrogate for stand age or forest structure, where each 1 km pixel was assigned a percentage forest density using several regression analyses between co-registered 1991 AVHRR data and classified Landsat Thematic Mapper data (Zhu and Evans 1992; Zhu 1994).

We reclassified the Forest Density layer into four classes:

Class #0: Non-forest (all non-forest Current Cover Types);
Class #1: 0%–32% forest density;
Class #2: 33%–66% forest density; and
Class #3: 67%–100% forest density.

Final biophysical spatial data

Succession diagrams

One of the most significant aspects of this project was the development of the succession diagrams; data from the succession diagrams were used to map Current Conditions as well as to refine all the input spatial data layers. Regional ecologists developed succession diagrams (Fig. 3) for each combination of ECOHUC, Kuchler PNV Group, and Historical Natural Fire Regimes, which we call the STRATUM, within their ECOREGION boundary. The succession diagram consists of a series of boxes ordered

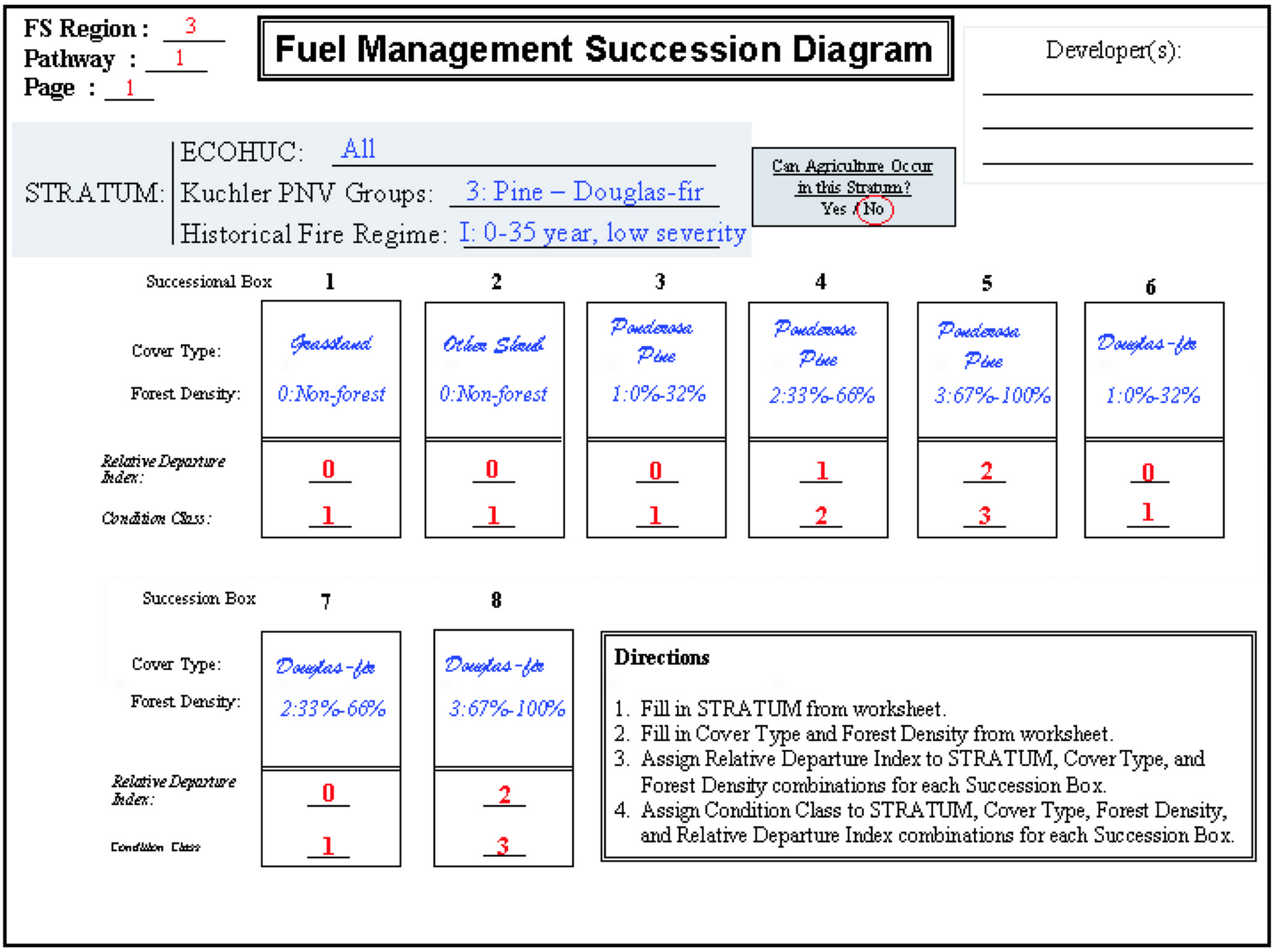


Fig. 3. Succession diagram example. Fields filled out in Blue indicate information provided by summary worksheets. Fields filled out in Red indicate information filled in by regional ecologists.

from seral to climax. Regional ecologists filled in these boxes with data provided in summary worksheets of all spatial combinations of Kuchler PNV Groups and Current Cover Types within an ECOREGION boundary. Hereafter, these boxes will be referred to as Succession Boxes. The succession diagram is a simplified version of the successional pathway diagrams described by Keane *et al.* (1996); they differ in that they lack the multiple pathways, real-time intervals, and probability links among vegetation types.

Regional ecologists completed the succession diagrams in three steps. First, they transferred the PNV Group and Historical Natural Fire Regime information from the summary worksheet to the STRATUM section of the succession diagram. They also filled in the Succession Boxes with Cover Type and Forest Density data provided by the worksheets. If the regional ecologists wanted to map combinations that did not occur in the worksheet or re-map a specific area, they filled in the succession diagrams with classes other than those provided by the worksheets.

Next, the ecologists assigned a Relative Departure Index to each succession box in the succession diagram based on the STRATUM, Cover Type and Forest Density data. The Relative Departure Index is a cumulative, incremental number relative to preceding succession boxes that are defined by the historical fire regime that reflects either vegetation composition (cover type and density) within historical ranges or changes in vegetation composition due to missed fire return intervals. Relative Departure Index values ranged from 0 to 3. A value of 0 indicates that the cover type and density class combination for that specific succession diagram's STRATUM is within its historical range. A value of 3 indicates that the cover type and density class combination for that specific succession diagram's STRATUM is cumulatively three increments from its historical conditions.

Once the Relative Departure Index was assigned, the regional ecologists completed the succession diagram by assigning a Current Condition Class, which was based on the STRATUM, species composition, structure, and Relative

Table 1. Condition Class descriptions
Condition classes are a function of the degree of departure from historical fire regimes resulting in alterations of key ecosystem components such as species composition, structural stage, stand age, and canopy closure. One or more of the following activities may have caused this departure: fire exclusion, timber harvesting, grazing, introduction and establishment of exotic plant species, insects and disease (introduced or native), or other past management activities

Condition class	Attributes	Example management options
Class 1	• Fire regimes are within or near an historical range • The risk of losing key ecosystem components is low • Fire frequencies have departed from historical frequencies by no more than one return interval • Vegetation attributes (species composition and structure) are intact and functioning within an historical range	Where appropriate, these areas can be maintained within the historical fire regime by treatments such as fire use
Class 2	• Fire regimes have been moderately altered from their historical range • The risk of losing key ecosystem components has increased to moderate • Fire frequencies have departed (either increased or decreased) from historical frequencies by more than one return interval. This results in moderate changes to one or more of the following: fire size, frequency, intensity, severity, or landscape patterns • Vegetation attributes have been moderately altered from their historical range	Where appropriate, these areas may need moderate levels of restoration treatments, such as fire use and hand or mechanical treatments, to be restored to the historical fire regime
Class 3	• Fire regimes have been significantly altered from their historical range • The risk of losing key ecosystem components is high • Fire frequencies have departed from historical frequencies by multiple return intervals. This results in dramatic changes to one or more of the following: fire size, frequency, intensity, severity, or landscape patterns • Vegetation attributes have been significantly altered from their historical range	Where appropriate, these areas may need high levels of restoration treatments, such as hand or mechanical treatments. These treatments may be necessary before fire is used to restore the historical fire regime

Departure Index found in each succession box. The ecologists assigned Current Condition Classes to combinations of vegetation composition, which are described by potential and current vegetation and stand density, and departure from historical fire regimes, which is defined as the alteration of the number of fire return intervals because of, but not limited to, fire suppression, grazing, removal of indigenous burning, or the introduction of exotic plant species. The three classes of current conditions and their respective potential management options are described in Table 1.

Review, modification, and completion of the spatial data

Several spatial data layers were mapped or subsequently modified from the information provided by the succession diagrams. The Current Condition Class layer was mapped and the Historical Natural Fire Regimes layer was modified. Additionally, problems in the Kuchler PNV Groups, Current Cover Types, and Forest Density Classes layers were corrected from the data provided by the succession diagrams.

All succession diagram assignments and changes were loaded into a database containing all STRATUM, Current Cover Types, and Forest Density combinations within the ECOREGION boundaries and linked to the GIS. We generated new spatial data layers of Historical Natural Fire Regime, Kuchler PNV Groups, Current Cover Types, Forest Density Classes, and Current Condition Classes for each ECOREGION boundary.

The final steps in the development of the vegetation-based data layers involved sending the maps produced from the workshops to the regional ecologists for final edits and resolving edge effects among ECOREGION boundaries. After we produced the new spatial data from the succession diagrams, we provided regional ecologists with new maps and worksheets. Maps included their ECOREGION boundary and the surrounding regions, allowing the ecologists to review how their assignments compared to other regions.

A final round of workshops, followed by an interactive editing process, was performed to resolve edge effects among ECOREGION boundaries created by assignments and mapping. Resolution of edge effects also relied on reference(s) to one or more of the following resources: (1) literature review of the Fire Effects Information System (FEIS) (Fischer *et al.* 1996); (2) expert knowledge of a specific area; or (3) majority opinion of regional ecologists from two or more ECOREGIONs.

Once all reviews and edits were applied to the GIS, final spatial data layers were generated for PNV Groups Version 2.0, Historical Natural Fire Regimes Version 3.0, Current Cover Types Version 1.0, and Current Condition Classes Version 1.0 (Fig. 2).

National fire occurrence data, 1986–1996

The National Fire Occurrence Database and GIS coverage includes Federal data from the USDA Forest Service (USFS) and four Department of Interior agencies: Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), National Park Service (NPS), and U.S. Fish and Wildlife

Service (FWS). It also includes non-Federal data from all conterminous states but Nevada.

Federal fire occurrence database

The federal database and GIS coverage consists of USDA Forest Service records from Regions 1 through 6, 8 and 9, and Department of Interior (DOI) fire records, including records from the Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), National Park Service (NPS), and U.S. Fish and Wildlife Service (FWS). Other federal agencies such as the Department of Defense, Bureau of Reclamation, and Department of Energy are not represented in this database.

USDA Forest Service fire database

USDA Forest Service units enter data from Report 5100-29 into their local databases and electronically submit the data to the national database called the National Interagency Fire Management Integrated Database (NIFMID) (USDA Forest Service 1993), located at the USDA National Information Technology Center in Kansas City, Missouri. Forest Service raw data were extracted from NIFMID for Forest Service regions covering the CONUS (Forest Service Regions 1–6, 8 and 9) for the years 1986–1996. An ArcInfo (ESRI 1991) coverage was generated from the latitude–longitude coordinates in the database and attributes were standardized to fit database items chosen for this project.

Department of the Interior fire database

The Department of Interior (DOI) agencies—BIA, BLM, FWS, and NPS—submit data from the DOI Form-1202 to the common Shared Applications Computer System, or SACS, located at the National Interagency Fire Center in Boise, Idaho. Initial DOI GIS layers, complete with attributes, were acquired from the BLM in January 1998. One GIS layer was provided for each DOI agency (FWS, BLM, BIA and NPS). After sending data and maps out for review to DOI agency fire directors, it was determined that too many inconsistencies occurred between our GIS database and the agencies' databases, chiefly due to differences in fire type and acreage summaries. As a result, we obtained new data directly from the DOI central database in October 1999 and worked closely with specific agencies to summarize appropriate fire types and acreages. These new data were used in the final product. An ArcInfo (ESRI 1991) coverage was generated from the databases' latitude-longitude coordinates, recorded in the database to the nearest second. Database items were standardized to fit the national database.

Processing of the Federal fire occurrence database

We performed several processing steps on both the USFS and DOI layers. We removed incorrectly recorded latitude or longitude coordinates from the Forest Service and DOI databases. Records from the USFS and DOI databases were removed that contained data not needed for this analysis such as pre-1986 data and records of false alarms, assist fires, and prescribed burns. In addition, a GIS layer of State boundaries was overlaid with the point layers to identify those points that did not occur within the recorded state. If the point occurred further than 10 km from the nearest State boundary to which it was assigned, or if the point occurred within 10 km of the State boundary but was not recorded as being in the adjacent state, it was removed from the GIS database.

Non-Federal fire database

Fire records were requested from all lower 48 states. Fire records in some form were obtained for all states except for Nevada. The completeness of the data received varied by State. Many States did not have complete fire records for all the years 1986 through 1996. In this case, we used whatever years were available if the data appeared complete for each year. If a State had years missing from the 1986–1996 time period but had complete data for 1997, the 1997 data were included. Quality of locations also varied by State. States provided fire locations as GIS coverages, UTM or Latitude–Longitude coordinates, legal descriptions, or with a County as the finest location. For nine states that were either unreachable or lacked digital fire data, data were obtained from the NFIRS database.

Processing of non-Federal fire database

We received non-Federal fire locations in a variety of formats. Fire records that were provided in a GIS format or with Latitude–Longitude or UTM coordinates were imported directly into the GIS. The fire locations recorded as legal descriptions were converted to point locations by processing them through an MS-DOS based conversion program (TRS2LL.exe, documentation available at http://www.crl.com/~wefald) or through one of two Arc Macro Language (AML) conversion programs, PLSFILE.AML and PLS2XY.AML (ESRI 1991) available at: http://www.wa.gov/ecology/gis/apps/pls2xy/pls2xy.htm). The TRS2LL.exe program converts township, range, and section to the corresponding latitude–longitude of the center of the section. The AMLs convert township, range, section and, if available, quarter, quarter section to the center of the section or quarter, quarter section. The AMLs require ArcInfo (ESRI 1991) polygon coverages of township, range, and section, otherwise known as Public Land Survey System (PLSS) coverages. State records that had County as the most precise fire location were assigned the center of the County as the fire location.

Because of the multitude of location sources from which non-Federal data came, several editing steps were performed prior to inclusion into the final database and GIS layer. After the conversion programs were run on the States that provided legal descriptions, the coverages were compared to the original PLSS layer. If the township, range, and/or section disagreed between the point layer and the PLSS, the record was discarded. Next, the point coverages were compared to the State and County layers. If the County and/or State disagreed between the point layer and the State-–County layer (outside of a 10 km buffer), then the record was discarded. These editing steps on the States that provided legal descriptions as the location source resulted in the deletion of between 0% (South Dakota) and 39% (Wyoming).

Of the State non-Federal records that had County as the most precise location, 0.3% of the records fell in Counties that had no State or private ownership and were therefore removed from the database. If the center of the County fell on Federal land, the fire locations were arbitrarily moved to non-Federal land within the County.

Attributes of State fire records were standardized to match the national database design**.** All State cause codes were standardized as best as possible to fit those used by the Federal agencies. For some States, the only available temporal data were date and time of dispatch or date and time the fire was declared ‘out’ (extinguished). These fields were loosely interpreted to be *Date Discovered* and *Date Controlled*, respectively. Records such as pre-1986 data and records of false alarms or prescribed burns were removed because they were not needed for this analysis.

For the States from which we did not receive data directly, records were obtained from the National Fire Incident Reporting System (NFIRS) database. Because participation in NFIRS is voluntary, the database does not represent all wildland fires within the State for any given time period. After State foresters reviewed summaries of the data, we determined that the NFIRS data were not a valid representation of State fire occurrence. As an example, NFIRS data are compared with data from four states (Kentucky, Louisiana, Alabama, and West Virginia) in Table 2. States with NFIRS data were given a status of unacceptable and these data were excluded from further consideration.

Potential Fire Characteristics layer

The Potential Fire Characteristics layer, Version 1, is a spatial representation of the number of days of high or extreme fire danger calculated from 8 years of historical National Fire Danger Rating System (NFDRS) data. The NFDRS characterizes the near upper limit, or near-worst-case scenario, of fire danger or fire potential for fires that could occur during a specific period, and is intended for mid- to large-scale applications. Deeming *et al.* (1977) note that ‘Fire-danger rating areas are typically greater than 100 000 acres and the weather is observed and predicted for one specific time during the day at one specific location’. The 1978 NFDRS indices are used throughout the lower 48 States to guide fire management planning activities (Deeming *et al.* 1977). The NFDRS Burning Index (BI) was developed to assess containment problems at the flaming front, and is used as the basis for the Potential Fire Characteristics layer (V1.0).

Fire danger versus fire behavior

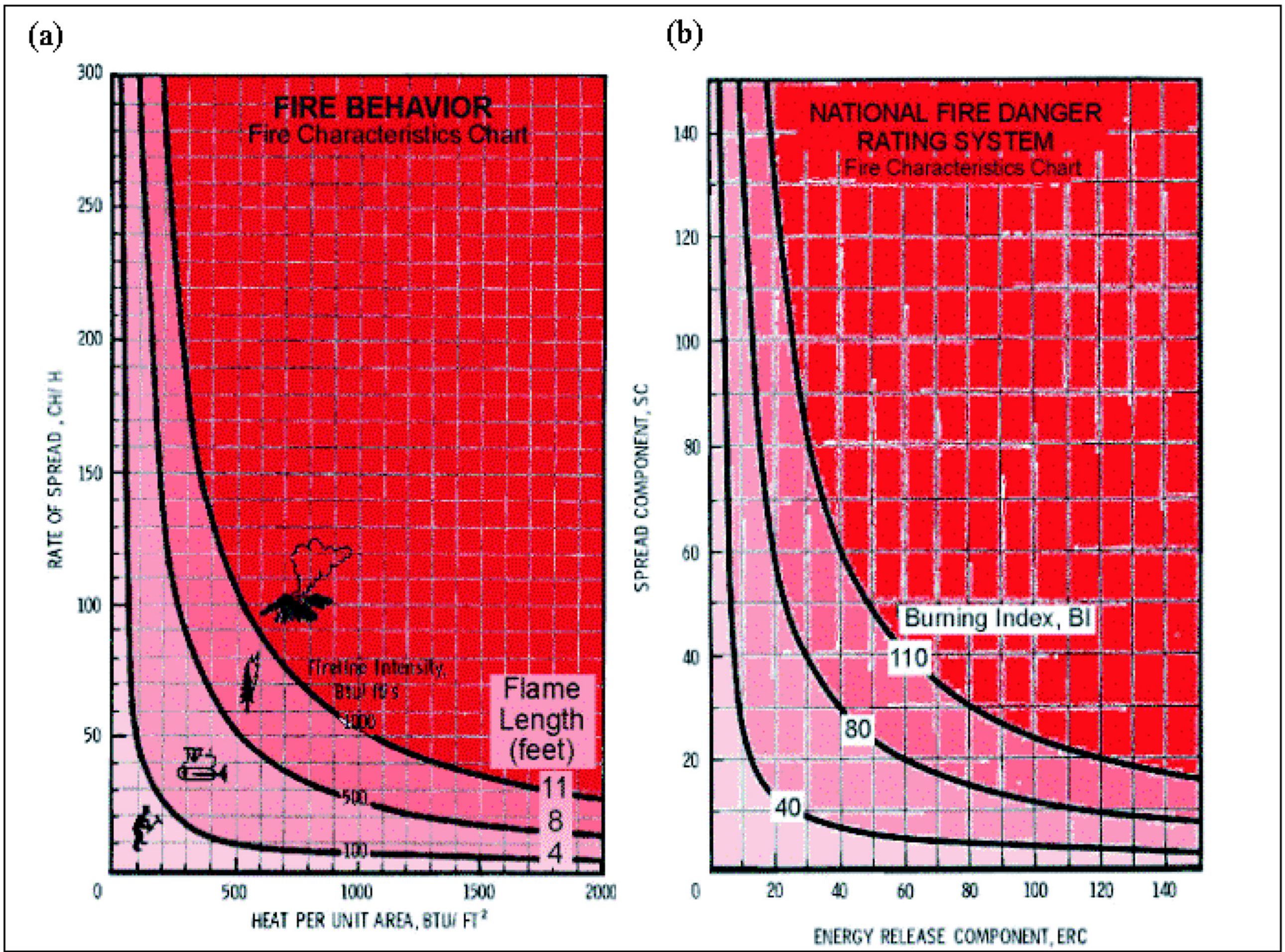
Large-scale fire danger ratings such as NFDRS, which are based on daily weather observations at fixed sites, must not be confused with site-specific fire predictions calculated by the Fire Behavior Prediction System (FBPS) (Andrews 1988). Although NFDRS and FBPS were developed for distinctly different applications, the two systems have similar computations (Cohen 1985). For example, both NFDRS and FBPS use the flame length equation developed by Byram (1959), but differ in the use of mass-weighting by NFDRS (Cohen 1985) and surface-area-to-volume ratio weighting by FBPS (Rothermel 1972). In FBPS, flame length is calculated to assess a specific fire behavior situation. In NFDRS, flame length, calculated by multiplying potential flame length by 10, is embedded in the BI. BI describes the magnitude of the fire containment problem in the context of coarse-scale, non-specific fire potential (Andrews and Rothermel 1981).

Interpreting fire danger indices

Because it is often difficult to interpret non-specific fire behavior information such as ‘the magnitude of the fire containment problem’, Andrews and Rothermel (1981) developed the concept of the ***fire characteristics chart*** to graphically display such information. Two forms of the chart are shown in Fig. 4: (1) the *Fire Behavior Fire Characteristics Chart*, with fireline intensity or flame length curves calculated from heat per unit area and rate of spread (Fig. 4*a*), and (2) the *National Fire Danger Rating Fire Characteristics Chart*, with BI calculated from Energy Release Component and Spread Component (Fig. 4*b*). Andrews and Rothermel (1981) and Rothermel (1983) also provide interpretations, developed explicitly for fire behavior predictions, of the magnitude of potential fire containment problems in terms of fire intensities and flame

Table 2. NFIRS fire data and State Foresters’ review data, 1987–1996 summaries

	NFIRS		State Reviews	
State	Total No. of fires	Total area (acres)	Total No. of fires	Total area (acres)
Alabama	168	Not reported	51 973	586 208
Kentucky	1191	Not reported	16 903	668 813
Louisiana	3206	Not reported	43 362	535 631
West Virginia	6294	Not reported	12 720	971 664



Fig, 4. The Fire Characteristics Charts: developed by Andrews and Rothermel (1981) (*a*) for Fire Behavior; and (*b*) for Fire Danger Rating.

lengths. Since BI is linearly related to flame length (Deeming *et al.* 1977), the BI curves shown in Fig. 4*b* can be converted to curves representing flame lengths by dividing the BI term by 10. We adapted the original table of fire characteristics interpretations (Andrews and Rothermel 1981) to reference BI-derived flame lengths, as shown in Table 3. Using the interpretations as an intuitive basis for visualizing potential fire characteristics, we selected the 8 ft (approx. 2.5 m) flame length threshold to indicate high or extreme fire potential.

Evaluating historical NFDRS data

Archived historical NFDRS data are available for most NFDRS weather stations, and are frequently used for evaluating the performance of fire danger rating system indices and also for defining threshold levels of potential fire danger (Andrews and Bradshaw 1997).

Historical daily weather data from over 2000 NFDRS weather stations can be accessed through the National Interagency Fire Management Integrated Database (NIFMID) (USDA Forest Service 1993), and corresponding NFDRS indices calculated from the daily weather are available through the Weather Information Management System (USDA Forest Service 1995). The NFDRS indices are not continuous spatial information; rather, they are calculated from point-specific weather station data and are based on one or more fuel model assignments for each respective weather station. A significant processing effort is required to use the NFDRS data in a continuous spatial context. This involves the interpolation of index values between weather stations. Burgan *et al.* (1997) have used an inverse-distance-squared interpolation algorithm to create continuous raster map layers of several NFDRS indices (including BI) for spatial applications. An individual map layer represents each day of historical data. These spatial data were used in the present project.

The flame length inputs to the Potential Fire Characteristics map layer were derived from 180 days of interpolated BI data (April–September), for each of 8 years (1989–1996). Each daily map layer was individually processed in two steps:

Step 1. Area-weighted mean BI values were calculated and summarized to the Fourth Code HUC polygons (Fig. 5).

Table 3. Fire potential interpretations for four flame length classes
Potential flame length is calculated as BI/10

BI	Flame length (ft)	Fire potential interpretation
≤40	≤4.0	• Fire can generally be attacked at the head or flank by persons using handtools • Handline should hold the fire
41–80	4.1–8.0	• Fires are too intense for direct attack on the head by persons using handtools • Handline cannot be relied on to hold fire • Equipment such as plows, dozers, pumpers, and retardant aircraft can be effective
81–110	8.1–11.0	• Fires may present serious control problems such as torching out, crowning, and spotting • Control efforts at the head of the fire will probably be ineffective
>110	>11.0	• Crowning, spotting, and major runs are probable • Control efforts at the head of the fire are ineffective

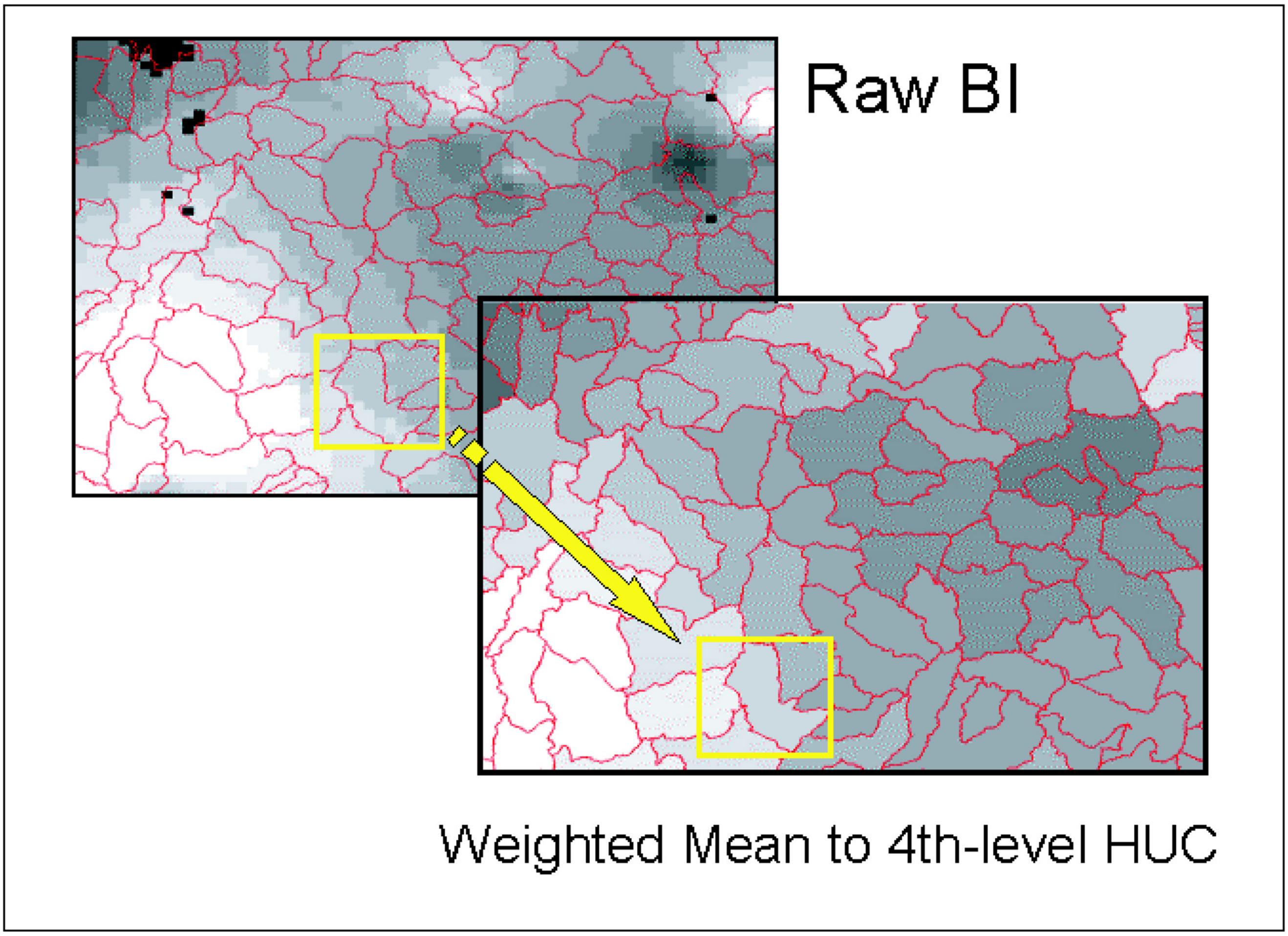


Fig. 5. Area-weighted mean BI values were calculated for each Fourth Code HUC, as shown in this example for 1 April 1991. In this procedure, each daily raster layer is converted to weighted-average polygon data.

Step 2. The area-weighted mean BI values for each Fourth Code HUC were then categorized into three potential flame length categories: ≤4.0 ft (1.2 m), 4.1–8.0 ft (12.5–2.4 m), and >8.0 ft (2.4 m). As an example, Fig. 6 shows the weighted-average data layer (Fig. 6*a*) and the three flame length categories (Fig. 6*b*) for 1 April 1991.

After each daily map layer was processed for a given year, the annual number of days that potential flame length 8 FT flame lengths were exceeded was determined for each sub-basin from the 8 years of data. The resulting map is Potential Fire Characteristics, Version 1.0.

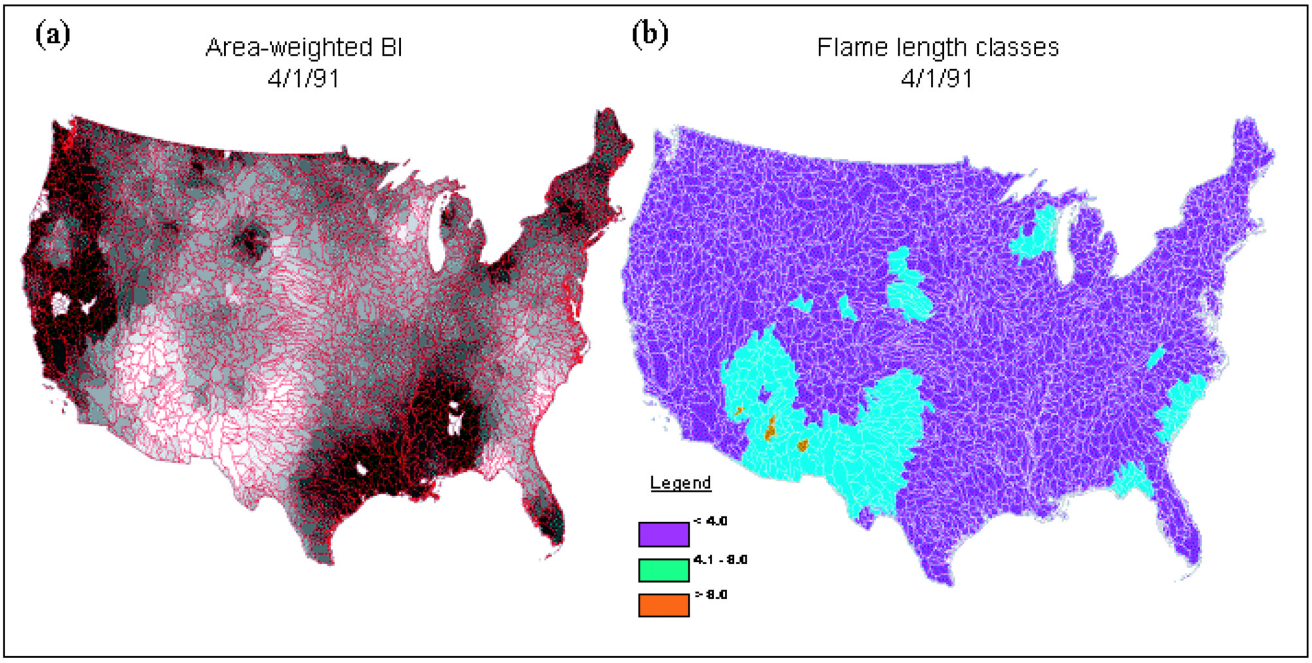


Fig. 6. The area-weighted mean BI data layer (*a*), and the three flame-length classes (*b*); both are for 1 April 1991.

Table 4. Population density classes by various units of area

Population class	Population per unit area				
	30×30" pixel	km^2	Acre	Mile^2	Mile^2 (rounded population)
Wildland	0–1	0–1.51	0–0.006	0–3.92	0–4
Rural	>1–10	>1.51–15.1	>0.006–0.06	>3.92–39.2	4–40
Mixed	>10–100	>15.1–151	>0.06–0.6	>39.2–392	40–400
Suburban	>100–500	>151–757	>0.6–3.1	>392–1960	400–2000
Urban	>500	>757	>3.1	>1960	>2000

Population Density groups

The Population Density map was developed to define Wildland–Urban Interface areas in the CONUS. We provided spatial data of human habitation and activity near wildland vegetation that posed a wildfire hazard. We used the LandScan Global Population 1998 Database developed by Oak Ridge National Laboratory (Dobson *et al.* 2000), a worldwide population database at a 30×30 second resolution, for estimating *ambient* population density classes. *Ambient* population refers the distribution of people across the landscape, taking into account travel patterns and diurnal movements. Traditional Bureau of Census 'residence' counts are based on night-time residences while ambient population counts account for where people travel and work. The database was developed using the best available census data to calculate probability coefficients for each cell based on road proximity, slope, land cover, and night-time lights. Verification and validation studies in the CONUS were conducted most extensively for the south-western United States.

We first clipped the global data set to the contiguous 48 States. We then classified the map into five population-density groups based on the number of people per cell. In the central U.S., a 30-second × 30-second cell contains about 0.7 km^2. Cells are larger to the south and smaller to the north. We used 0.7 km^2 as the average cell size to calculate different population densities. The population density classification is shown in Table 4.

We compared these population densities with maps of current vegetation to identify two spatial situations: (1) the classic wildland–urban *interface*, where dense populations live near wildland vegetation; and (2) the wildland–urban *intermix*, where people and their activities are scattered more loosely throughout those wildland vegetation areas (Davis 1987). We first excluded the pixels where the dominant land cover type was agriculture, water, or barren, since we were

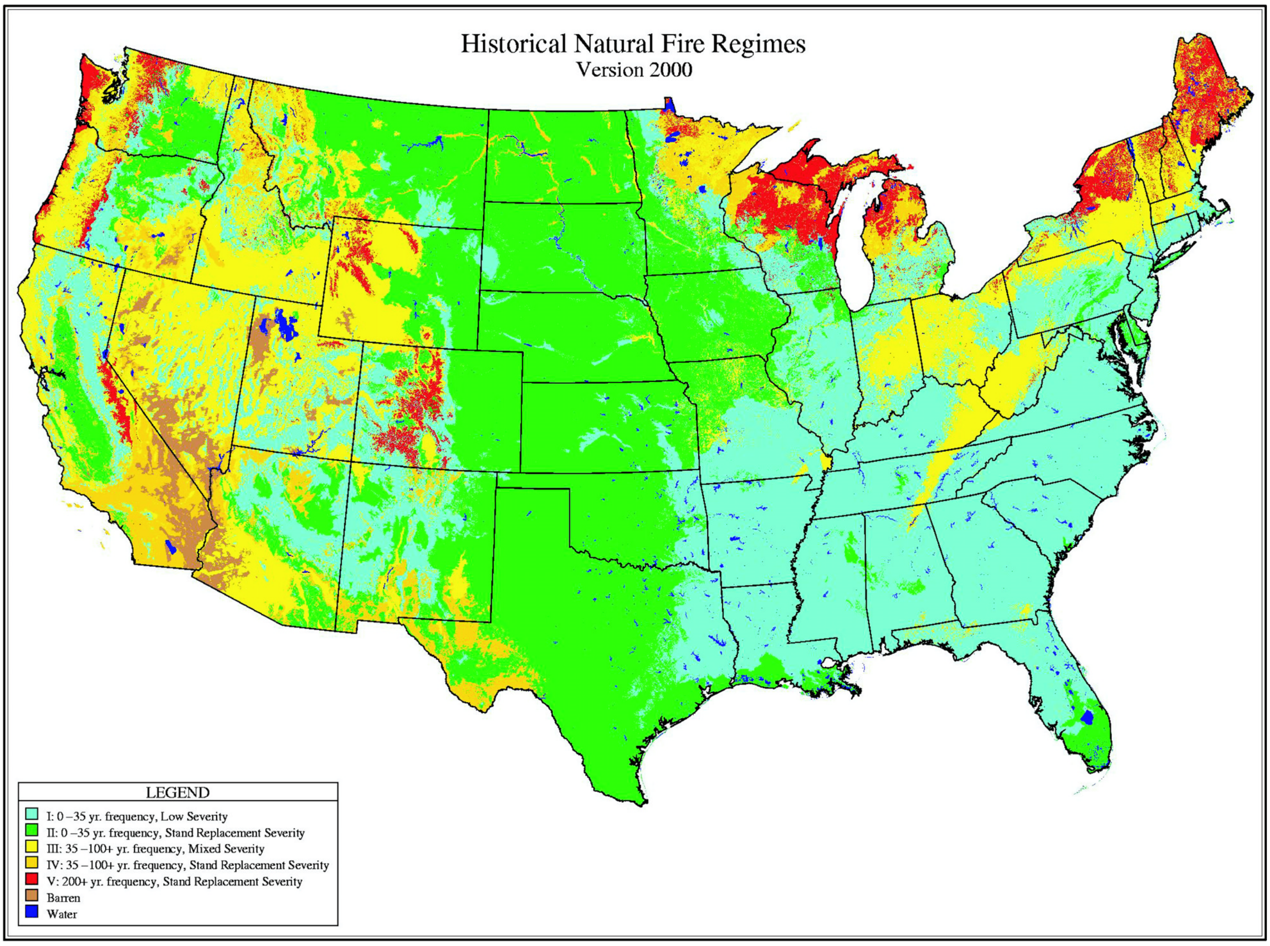


Fig. 7. Five fire regimes are depicted on The Historical Natural Fire Regimes layer (version 2000).

not interested in population density in those cover types for this exercise. We then identified the *interface*, those urban or suburban pixels that were directly adjacent to rural or wildland pixels. The mixed population density range of 40–400 people per square mile was assigned to the *intermix* category. The sum of the two, in this analysis, represents what we have defined as the wildland–urban interface. Finally, to compare the Population Density map with this project's vegetation layers, we resampled the LandScan data into 1-km^2 grids.

Results

Vegetation-based data layers

The coincidence of various vegetation-based data layers provides insight regarding the current condition of vegetation. For example, the Historical Natural Fire Regimes layer (Fig. 7) was developed specifically for this purpose—to be used as a biophysical baseline against which current conditions can be contrasted. Coincidence tables can be generated using the Current Conditions layer (Fig. 8) to assess the distribution of current conditions with respect to the biophysical baseline conditions. The distribution of area by Historical Natural Fire Regime and all Cover Types (except agriculture, barren, water, and urban / development / agriculture) is shown in Table 5, where Condition Class 1 and the 0–35 year frequency / low severity Historical Natural Fire Regime (I) comprise the highest proportion (48% and 34%, respectively) of the CONUS land area. When combined, Condition Classes 2 and 3 comprise over 50% of the total CONUS land area.

National fire occurrence, 1986–1996

Summaries of fire frequency and area burned by State are shown in Table 6. Non-federal data for many states are incomplete. Fig. 9 illustrates the number of years of missing non-federal data for each state for the 11 year period 1986–1996.

Population density groups

Fourteen percent of the population lives in the Wildland-Urban Interface, which comprises 562 824 km^2, or approximately 7%, of the total CONUS land area (Table 7). We compared the suburban and urban classifications to map

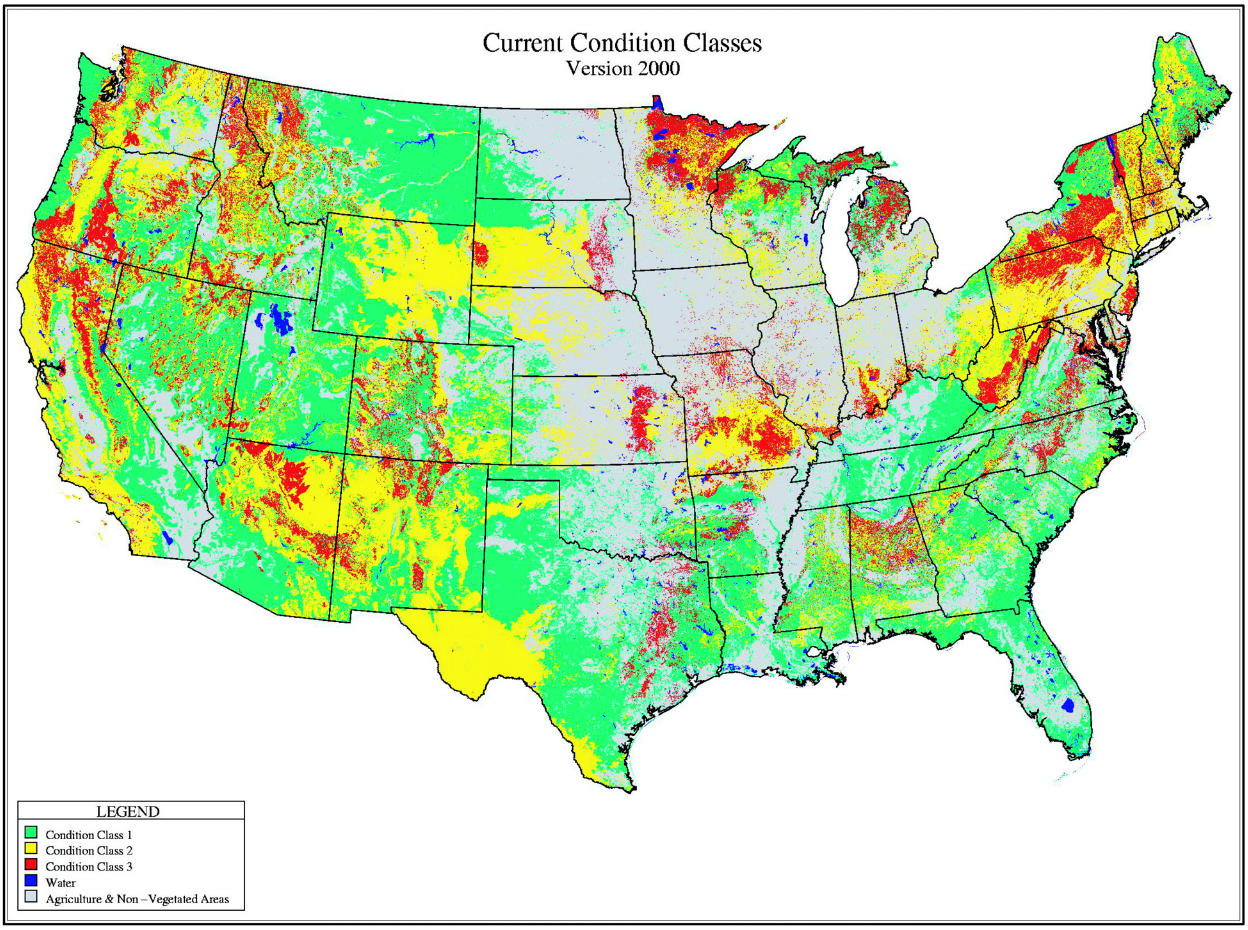


Fig. 8. Three condition classes are mapped in the Current Conditions layer (version 2000).

products showing Bureau of Census-defined urban areas in Colorado and Rhode Island, and they matched well. The wildland classification seemed straightforward, since it identified areas where virtually no ambient population was located. The rural and mixed categories were undefined elsewhere, however, so these classes were field-checked with experts around the country to see if they represented an appropriate population density for this exercise.

Discussion

We successfully completed the development of seven spatial data layers for the CONUS in support of national fire and fuel management planning efforts, using the best available spatial data and methodologies. We developed data and maps for current vegetation conditions as well as of vegetation, fire occurrence, and wildland–urban interface maps.

Of the land area in the CONUS, 50% is beyond its historical range in terms of fire regimes, fuel loadings, and vegetation attributes with 32%occurring in historically high frequency fire regimes. Of particular interest are the areas in these high frequency fire regimes because populations tend to concentrate in the lower elevations in which these fire regimes occur.

Because the four vegetation-based data layers were based on pre-existing maps or spatial data, scale inconsistencies may cause some error in the data layers. Many edits were made to the Kuchler map because of scale differences between the course polygon delineations of the Kuchler PNV and the finer scale, continuous data of the DEM used in the terrain matching. We edited the PNV Group layer by overlaying it with the cover type layer to adjust conflicting combinations. We integrated the two best available continuous current cover type layers to create the Current Cover Type layer, Version 1.0, but different methodologies used to develop these two layers caused spatial registration problems, such as large water bodies not overlaying, forcing us to shift the data up to 2 km. We further edited the layer by adjusting the cover types to be consistent with the PNV Groups and fire regime data. Because the Historical Natural Fire Regimes product was developed from these vegetation maps, any spatial inconsistencies would have been carried through to this layer.

Developers of spatial products with inherent grain resolution as coarse as these (nominal mapping unit of 1 km^2, and realized information grain much coarser than that) have no way of statistically characterizing either the

Table 5. Historical fire regimes by condition classes land area summary
Table includes all ownerships and all cover types except agriculture, barren, water, and urban / development / -agriculture

Historical natural fire regime	Area in condition class (km^2, %)							
	Class 1		Class 2		Class 3			
	km^2	Row %	km^2	Row %	km^2	Row %	Total km^2	Total %
I. 0–35 year frequency, low severity	704 647	41	700 124	41	309 970	18	1 714 741	34
II. 0–35 year frequency, stand replacement	770 177	57	532 725	40	41 385	3	1 344 286	27
III. 35–100+ year frequency, mixed severity	510 572	43	449 032	38	216 012	18	1 175 616	24
IV. 35-100+ year frequency, stand replacement	212 251	43	141 335	29	140 114	28	493 700	10
V. 200+ year frequency, stand replacement	194 233	72	54 827	20	19 623	7	268 683	5
Column total, Column %	2 391 880	48	1 878 043	38	727 104	15	4 997 027	100

spatial or contextual accuracy of their products. The classical method of 'ground-truth' verification and quantification through error matrices or contingency analysis is not possible—there are far too many classes in some of the input data layers (for example, 159 in the Land Cover Characterization Database) to implement a valid field campaign for 'ground-truthing'. Therefore, it remains the reader's or user's burden, unfortunately, to refer to documentation and references accompanying each of the underlying data products used in an integrated effort such as the one presented here. Beyond that, the user should recognize and acknowledge situations in which expected errors propagate or carry forward. We have attempted to do that here.

Condition class

One of the most significant aspects of this project was the development of the succession diagrams. The methodology used to develop the succession diagrams can be used to assign other ecosystem attributes such as insect and disease infestation levels, smoke production, and hydrologic and soil processes. This pathway approach, as well as the integration of multiple data layers, can be applied to multiple scales—from a national level (as was done for this project) to a local level such as a national forest or district.

We considered five ecosystem attributes which help to characterize ecological systems: disturbance regimes (patterns and frequency of insect, disease, fire, etc.); disturbance agents; smoke production; hydrologic function (sedimentation, stream flow, etc); and vegetative descriptors (composition, structure, and resilience to disturbance agents). These are integrated into descriptions of the three classes of current conditions and potential management actions:

Condition class 1

Historical ecosystem attributes of disturbance regimes (patterns and frequencies of insect, disease, and fire), disturbance agents, smoke production, hydrologic function (sedimentation, stream flow, etc.), and vegetative attributes (composition, structure, and resilience to disturbance agents) are largely intact and functioning within an historical range. These areas can be maintained in a natural fire regime by prescribed fire with minimal if any mechanical treatment.

Condition class 2

Historical ecosystem attributes have been moderately altered. One or more fire return intervals have been missed, resulting in increased fire sizes, intensities, severities, and coarser landscape patterns, or fire frequency and intensities have increased due to the introduction and establishment of exotic plant species. These areas may need some mechanical treatments in addition to prescribed fire to be restored to natural fire regimes.

Condition class 3

Ecosystem attributes have been significantly altered. Multiple fire return intervals have been missed resulting in dramatic departures from historical conditions, or fire frequency and intensities have increased due to the introduction and establishment of exotic plant species. Mechanical treatment must be implemented to these areas before prescribed fire can be introduced.

National fire occurrence, 1986–1996

Although we invested nearly 2½ person-years of effort in our attempt to develop a single, 'wall-to-wall' National Fire Occurrence Database, this is clearly not yet possible. While

Table 6. Federal and non-Federal fire occurrence, by state, 1986–1996

State	Federal fires		Non-Federal fires		Total (all ownerships)	
	No. of fires	Area burned (km^2)	No. of fires	Area burned (km^2)	No. of fires	Area burned (km^2)
Alabama	1 230	106	168	0	1 398	106
Arizona	31 548	4 326	9 201	2 571	40 749	6 897
Arkansas	1 853	116	23 626	1 116	25 479	1 232
California	36 751	10 337	101 144	6 467	137 895	16 804
Colorado	10 182	1 011	4 868	500	15 050	1 511
Connecticut	2	0	1 268	16	1 270	16
Delaware	19	13	401		420	13
District of Col.	32	0	0		32	0
Florida	3 182	1 624	51 519	4 709	54 701	6 333
Georgia	1 229	131	91 935	1 492	93 164	1 623
Idaho	16 416	16 595	5 169	2 357	21 585	18 952
Illinois	362	20	1 201		1 563	20
Indiana	668	21	14 004	291	14 672	312
Iowa	102	10	378		480	10
Kansas	191	59	74 933	7 148	75 124	7 207
Kentucky	1 641	293	1 191		2 832	293
Louisiana	1 386	428	3 206		4 592	428
Maine	62	1	7 564	96	7 626	97
Maryland	123	13	5 850	157	5 973	170
Massachusetts	52	0	29 677	156	29 729	156
Michigan	839	51	6 166	229	7 005	280
Minnesota	3 556	964	18 482	2 206	22 038	3 170
Mississippi	2 882	358	39 427	2 213	42 309	2 571
Missouri	2 559	328	18 457	1 235	21 016	1 563
Montana	13 787	5 638	4 467	1 582	18 254	7 220
Nebraska	590	391	14 672	2 420	15 262	2 811
Nevada	7 128	4 883	0		7 128	4 883
New Hampshire	38	1	1 484		1 522	1
New Jersey	81	1	11 237	277	11 318	278
New Mexico	10 986	3 385	7 397	4 936	18 383	8 321
New York	404	6	4 412	172	4 816	178
North Carolina	1 494	271	51 017	4 352	52 511	4 623
North Dakota	4 355	368	3 087	447	7 442	815
Ohio	481	16	2 412	60	2 893	76
Oklahoma	2 617	356	16 781	2 071	19 398	2 427
Oregon	20 851	7 556	13 083	1 064	33 934	8 620
Pennsylvania	174	5	9 124	239	9 298	244
Rhode Island	3	0	335		338	0
South Carolina	1 098	66	28 616	620	29 714	686
South Dakota	6 583	862	382	187	6 965	1 049
Tennessee	1 161	111	9 528	365	10 689	476
Texas	2 089	899	14 262	1 065	16 351	1 964
Utah	8 335	4 236	4 891	2 837	13 226	7 073
Vermont	10	1	942	8	952	9
Virginia	809	102	4 167	76	4 976	178
Washington	7 514	1 965	12 892	852	20 406	2 817
West Virginia	240	10	6 294		6 534	10
Wisconsin	1 333	29	19 197	189	20 530	218
Wyoming	3 872	5 898	3 235	772	7 107	6 670
TOTAL	212 900	73 861	753 749	57 550	966 649	131 411

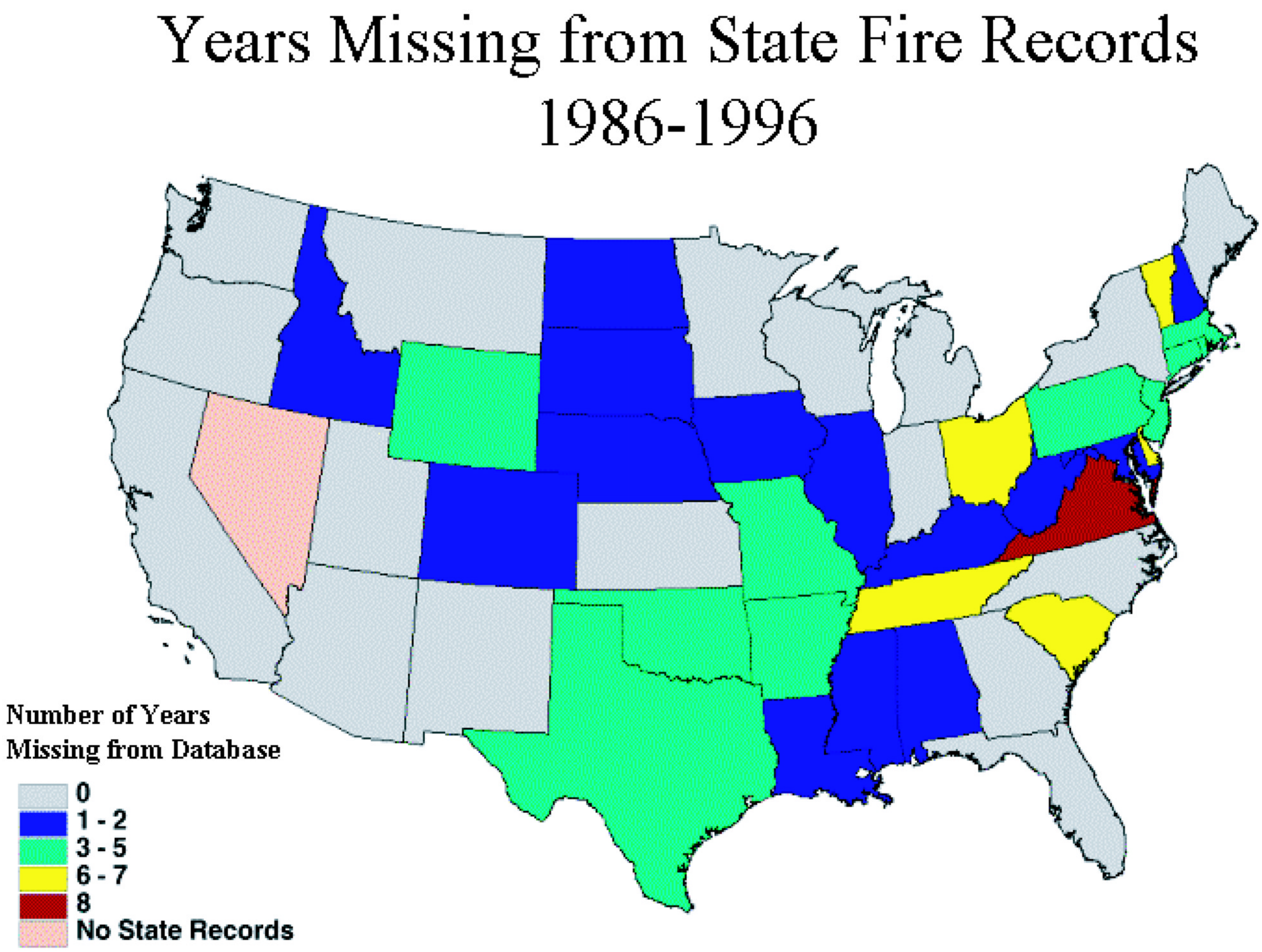


Fig. 9. The number of years of missing non-Federal data for each State for the 11 year period 1986–1996.

the Federal database has been verified by each Federal agency as being representative of the full 11 year time period 1986–1996, several States have years missing from this time period. Several States did not send spatially complete databases, with some Counties having few or no fire records, such as Alabama, Oklahoma, Texas, and Ohio. We were unable to obtain any non-Federal records for Nevada.

Duplicate State and Federal records for the same fire may exist in the databases. Fires on Federal land may also be recorded by the State (Bunton 1999). Because fire locations are generally very coarse and not all database fields that could aid in tracking duplicates are fully populated, it was virtually impossible to track fires duplicated between the Federal and State databases.

While problems like different cause codes or absence of key data fields can be documented, it is not known to what extent wildland fires from States' urban and rural jurisdictions go unreported. Fires from volunteer rural firefighting organizations may not be reported to a centralized agency such as State Fire Marshals or State Foresters (Stuever *et al.* 1995). For example, the Forestry Division of Montana's Department of Natural Resources, located in western Montana, rarely receives fire reports from central or eastern Montana fire departments. This tendency of under-reporting may explain the relative absence of fires in all but the eastern-most portion of Oklahoma.

Collecting, compiling, and summarizing national fire occurrence data was a time-consuming and often difficult process. Multiple requests of State agency representatives were often necessary before data were received. Once data were received, pre-GIS processing time was extensive because of the wide variety of formats received. GIS processing time was also extensive given the assortment of location types we received. Individual States' database editing may be an ongoing process, as was the case with California, rendering the data obsolete a year after receiving it. Once data were incorporated into the GIS, further review and processing were necessary before appropriate data summaries were acceptable, as was the case with Department of Interior data. Despite the time invested in acquiring and synthesizing data, inconsistencies still exist, primarily because most fire data are managed as databases, not as GIS databases. Until fire reporting is standardized and mandatory for all jurisdictions, this type of product will have

Table 7. Population class land distribution

Population land use class	Area (km^2)	Percentage land use	Approx. population	Percentage population
Wildland	3 386 241	44	1 216 103	0.45
Rural	1 333 798	17	8 831 385	3.00
Wildland–urban interface	562 824	7	38 573 910	14.00
Suburban	152 022	2	49 709 586	19.00
Urban	63 086	1	138 260 218	51.00
Agriculture	2 153 110	28	30 412 573	11.00
Water	89 516	1	1 027 117	0.38
Other	43 895	1	471 501	0.18
Total	7 784 492	100	268 502 393	100

its limitations as to the dependability and usefulness of the data as an exact representation of fire occurrence, but it can be used to illustrate trends in fire occurrence. These data should be used with caution because of the various levels of data quality.

Potential fire characteristics, Version 1.0

These data have limited application at any level other than national, programmatic, or strategic planning. Although the concept and application of NFDRS indices has been widely accepted since the late 1970s, continuous spatial coverages of these data clearly bring out 'the worst' in the data. Perhaps the most limiting factor is the exceedingly low spatial and temporal density of weather observations. The spatial density is defined simply by the number and distribution of acceptable NFDRS reporting stations—only about 2000 are used for the entire CONUS. Values between stations are estimated with an inverse distance-squared technique on a 10-km grid. Burgan *et al.* (1997) have noted that this works pretty well in areas of relatively high station density, such as in the western United States, but has obvious shortcomings in other areas, particularly for the Central and Eastern States. This shortcoming is also noted on the website for the Wildland Fire Assessment System: http://fs.fed.us/land/wfas (USDA Forest Service 1998).

In terms of temporal resolution, the NFDRS weather observation protocol is once-daily reporting at 2:00 p.m., the theoretical worst-case fire-weather period. This greatly limits the resolution of the very dynamic fire-related weather observations.

Population density groups

The spatial data of wildland–urban interface areas could be used to locate priority fuel management areas. The population density map can also be used to evaluate other fire- and resource-related management issues where proximity and activity of people becomes important to management planning and action.

How have these data been used?

These spatial data were posted on a national USFS website immediately following the completion of the draft map products. The final versions (Version 2000) are now on the website, and are available for use or reference. The website is found at http://fs.fed.us/fire/fuelman. In addition to PC-compatible graphic products for each layer, the website site includes documentation, metadata, and ArcInfo (ESRI 1991) GIS map graphics and data coverages. All data and relevant documentation can also be found in a report to be published as a CD-ROM by the USDA Forest Service, Rocky Mountain Research Station.*

The Historical Natural Fire Regime and Current Condition products were adopted by the USDA Forest Service as the keystone reference data in support of the agency's 'Cohesive Strategy' report, *Protecting People and Sustaining Resources in Fire-Adapted Ecosystems* (USDA Forest Service 2000) as well as the interdepartmental National Fire Plan, *Managing the Impact of Wildfires on Communities and the Environment* (USDA Forest Service and US Department of the Interior 2000). The data were also applied to analyses relating to the agency's Roadless Area Conservation Final Rule (USDA Forest Service 2001).

Non-governmental resource managers have used these data as well. For example, The Nature Conservancy is utilizing these data in resource assessment and development of conservation strategies for the CONUS.†

What's next?

This paper has presented only one integrated effort at developing 'wall-to-wall' (CONUS) spatial products for 'triage-like' applications. The coarse grain of these data has been the focus of the greatest concern. While the data were

* Schmidt KM, Menakis JP, Hardy CC, Hann WJ, Bunnell DL. [in prep.]. Development of coarse-scale spatial data for wildland fire and fuel management. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-CD. Ogden, UT.

† Personal communications, Paula Seamon, TNC Fire Management.

provided with explicit caveats regarding summaries or applications over areas smaller than States or Forest Service Regions, many users have been 'tempted' to do just that. In turn, we have been asked by resource managers, as well as U.S. Congressional delegates, to substantiate our reluctance to apply the data at smaller scales.

The needs of users to acquire spatial data similar to these, yet with finer grain, are clearly evident, and the next phase of activity will be the development of the same suite of vegetation-based layers at a mid and fine scale for input to a land and fire computer management tool, called LANDFIRE, being developed at the Fire Modeling Institute. To improve condition class assignments, the succession diagrams will be redone for fine- to mid-scales. The development protocols will differ significantly, however, because the mid- and fine-scale data must be more process-based and reproducable at regular intervals. Accuracy assessments will also be not only possible, but required, for data products developed at mid- to fine-scales. Both the development and the assessment activities will rely heavily on extensive field verification data.

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